METHODS FOR PRODUCING ELECTRON-EMITTING DEVICE, ELECTRON SOURCE, AND IMAGE-FORMING APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to methods for producing an electron-emitting device, an electron source comprised of a plurality of such electron-emitting devices, and an image-forming apparatus such as a display device or the like constructed using the electron source.

Related Background Art

The conventionally known electron-emitting devices are generally classified under two types, thermionic electron-emitting devices and cold-cathode electron-emitting devices. The cold-cathode electron-emitting devices include field emission type (hereinafter referred to as "FE type") devices, metal/insulator/metal type (hereinafter referred to as "MIM type") devices, surface electron-emitting devices, and so on.

Examples of the FE type devices include those disclosed in W. P. Dyke and W. W. Dolan, "Field Emission," Advance in Electron Physics, 8, 89 (1956) or in C. A. Spindt, "Physical Properties of thin-film field emission cathodes with molybdenum cones," J. Appl. Phys., 47, 5248 (1976), and so on.

Examples of the MIM type devices ~~known~~ include

those disclosed in C. A. Mead, "Operation of Tunnel-

Emission Devices," J. Appl. Phys., 32, 646 (1961), and

so on.

5   Examples of ~~the~~ surface conduction electron-

emitting devices include those disclosed in M. I.

Elinson, Radio Eng. Electron Phys., 10, 1290 (1965),

and so on.

~~The surface~~ conduction electron-emitting devices

10   utilize ~~such~~ a phenomenon that electron emission occurs

when electric current is allowed to flow in parallel to

the surface in a thin film of a small area formed on an

insulating substrate.   Examples of ~~the~~ surface

conduction electron-emitting devices reported

15   heretofore include those using a thin film of SnO_2 by

Elinson et al. cited above, those using a thin film of

Au [G. Dittmer: "Thin Solid Films," 9, 317 (1972)],

those using a thin film of In_2O_3/SnO_2 [M. Hartwell and

C. G. Fonstad: "IEEE Trans. ED Conf.," 519, (1975)],

20   those using a thin film of carbon [Hisashi Araki et

al.: Shinku (Vacuum), Vol. 26, No. 1, p22 (1983)], and

so on.

A typical example of these surface conduction

electron-emitting devices is the device structure of M.

25   Hartwell cited above, which is schematically shown in

Fig. 18.   In the same drawing, numeral 1 designates a

substrate.   Numeral 4 denotes an electrically

conductive film, which is, for example, a thin film of a metallic oxide formed in an H-shaped pattern and in which an electron-emitting region 5 is formed by an energization operation called energization forming

5 described hereinafter. In the drawing the gap L between the device electrodes is set to 0.5-1 mm and the width W' to 0.1 mm.

In these surface conduction electron-emitting devices, it was common practice to preliminarily

10 subject the conductive film 4 to the energization operation called energization forming, prior to execution of electron emission, thereby forming the electron-emitting region 5. Specifically, the energization forming is an operation for applying a

15 voltage to the both ends of the conductive film 4 to locally break, deform, or modify the conductive film 4, thereby forming the electron-emitting region 5 in an electrically high resistance state. In the electron-emitting region 5 a fissure is formed in part of the

20 conductive film 4 and electrons are emitted from near the fissure.

The surface conduction electron-emitting devices described above have an advantage of capability of forming an array of many devices across a large area,

25 because of their simple structure. A variety of applications have been studied heretofore in order to take advantage of this feature. For example, they are

applied to charged beam sources, and image-forming

apparatus such as display devices and the like.

An example of the conventional application to

formation of an array of many surface conduction

electron-emitting devices is an electron source

comprised of a lot of rows (in a ladder-like

configuration), each row being formed by arraying the

surface conduction electron-emitting devices in

parallel and connecting the both ends (the both device

electrodes) of the individual surface conduction

electron-emitting devices by wires (common wires) (for

example, Japanese Laid-open Patent Applications No. 64-

31332, No. 1-283749, and No. 2-257552).

Particularly, in the case of the display device,

it can be formed as a plane type display device,

similar to the display device made using the liquid

crystal, and an example suggested as a self-emission

type display device necessitating no back light is a

display device comprised of a combination of an

electron source consisting of a lot of surface

conduction electron-emitting devices with a fluorescent

member which emits visible light under irradiation with

electron beams from the electron source (United States

Patent No. 5,066,883).

There are some conventional methods known as

methods for producing the surface conduction electron-

emitting devices described above. For example, a

variety of methods, including vacuum vapor deposition,
sputtering, chemical vapor deposition, dispersion
coating, dipping coating, spinner coating, ink jet
process (EP-A-0717428), and so on, are known as methods
for forming the electroconductive film to be subjected
to the above energization forming operation. The known
energization forming methods on the electroconductive
film include a method for energizing the
electroconductive film while heating a substrate on
which the electroconductive film is laid (Japanese
Laid-open Patent Application No. 64-019658), a method
for energizing the electroconductive film under a
reducing ambience (Japanese Laid-open Patent
Application No. 6-012997, EP-A-0732721), and so on.

In formation of the electroconductive film, it is
desirable to form the film in uniform thickness in
order to obtain good electron emission characteristics.
There appear, however, differences in the uniformity,
depending upon differences among the methods employed.
Further, in the energization forming operation, particularly,
where the forming operation of individual conductive
films is carried out through wires to which the many
conductive films are connected, thereby forming
electron-emitting regions therein, it is desirable to
perform such forming operation as to minimize
variations in the electron emission characteristics
among the individual conductive films. However,

differences become greater in the variations of the characteristics as the number of electroconductive films connected increases.

5   SUMMARY OF THE INVENTION

An object of the present invention is to provide methods for producing an electron-emitting device capable of presenting good electron emission characteristics, an electron source incorporating such

10   electron-emitting devices, and an image-forming apparatus.

Another object of the present invention is, particularly, to provide methods for producing an electron-emitting device capable of presenting good

15   electron emission characteristics, independent of a method for forming its electroconductive film, an electron source incorporating such electron-emitting devices, and an image-forming apparatus.

Another object of the present invention is,

20   particularly, to provide methods for producing an electron-emitting device capable of presenting good electron emission characteristics even with the energization operation on an electroconductive film having some thickness irregularities, an electron

25   source incorporating such electron-emitting devices, and an image-forming apparatus.

Another object of the present invention is,

particularly, to provide a method for producing an electron source having a plurality of electron-emitting devices with less variations in the electron emission characteristics.

5   Another object of the present invention is to provide a method for producing an image-forming apparatus capable of forming a higher-quality image.

For accomplishing the above objects, the present invention provides a method for producing an electron-

10   emitting device comprising an electroconductive film having an electron-emitting region between electrodes, wherein a step of forming said electron-emitting region in the electroconductive film comprises a step of heating the electroconductive film and a step of

15   energizing the electroconductive film, in an atmosphere in which a gas for promoting cohesion of the electroconductive film exists.

The present invention also provides a method for producing an electron-emitting device comprising an

20   electroconductive film having an electron-emitting region between electrodes, wherein a step of forming said electron-emitting region in the electroconductive film comprises a step of energizing the electroconductive film while heating the

25   electroconductive film, in an atmosphere in which a gas for promoting cohesion of the electroconductive film exists.

The present invention also provides a method for producing an electron source having a plurality of electron-emitting devices, wherein said electron-emitting devices are produced by either of the above-described methods for producing the electron-emitting device.

The present invention also provides a method for producing an image-forming apparatus comprising an electron source having a plurality of electron-emitting devices and an image-forming member for forming an image under irradiation of electrons from the electron source, wherein said electron-emitting devices are produced by either of the above-described methods for producing the electron-emitting device.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A, 1B and 1C are schematic structural diagrams showing a plane type surface conduction electron-emitting device as an embodiment of the electron-emitting device of the present invention;

Figs. 2A, 2B and 2C are diagrams showing a method for producing an electron-emitting device of the present invention;

Fig. 3 is a schematic plan view showing an electron-emitting device in Example 1 of the present invention;

Figs. 4A and 4B are diagrams showing examples of

forming waveforms;

Fig. 5 is a schematic structural diagram showing an example of a vacuum process apparatus according to the present invention;

Fig. 6 is a diagram showing emission current vs. device voltage characteristics (I-V characteristics) of the electron-emitting device of the present invention;

Fig. 7 is a schematic structural diagram showing an electron source of a simple matrix configuration as an embodiment of the electron source of the present invention;

Fig. 8 is a schematic structural diagram of a display panel used in an embodiment of the image-forming apparatus of the present invention incorporating an electron source having a simple matrix configuration;

Figs. 9A and 9B are diagrams showing fluorescent films in the display panel illustrated in Fig. 8;

Fig. 10 is a diagram showing an example of driving circuitry for driving the display panel illustrated in Fig. 8;

Fig. 11 is a schematic structural diagram showing an electron source of a ladder-like configuration as an embodiment of the electron source of the present invention;

Fig. 12 is a schematic structural diagram of a display panel used in an embodiment of the image-

forming apparatus of the present invention

incorporating the electron source of the ladder-like

configuration;

Fig. 13 is a schematic plan view showing an

electron source in Example 3 of the present invention;

Fig. 14 is a sectional view along section line 14-14 in Fig.

13;

Figs. 15A, 15B, 15C and 15D are schematic

sectional views showing production steps of the

electron source in Example 3 of the present invention;

Figs. 16E, 16F and 16G are schematic sectional

views showing production steps of the electron source

in Example 3 of the present invention;

Fig. 17 is a block diagram of an embodiment of the

image-forming apparatus of the present invention;

Fig. 18 is a schematic structural diagram showing

a conventional plane type surface conduction electron-

emitting device;

Fig. 19 is a schematic diagram of an apparatus

used for production of the image-forming apparatus of

the present invention;

Fig. 20 is a schematic diagram showing an example

of a connection state of each device in the forming

step in production of the image-forming apparatus of

the present invention; and

Fig. 21 is a schematic plan view showing an

example of the conventional electron-emitting devices.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described in detail with an example of the plane type surface conduction electron-emitting device as a preferred embodiment of

5   the present invention.

Figs. 1A, 1B and 1C are schematic diagrams to show an embodiment of the plane type surface conduction electron-emitting device, wherein Fig. 1A is a plan view, Fig. 1B is a sectional view along _section line_ 1B-1B in Fig.

10   1A, and Fig. 1C is a sectional view along _section line_ 1C-1C in Fig. 1A.   In Figs. 1A, 1B and 1C, reference numeral 1 designates a substrate, 2 and 3 device electrodes, 4 an electroconductive film, and 5 an electron-emitting region.   As illustrated in Figs. 1A, 1B, and 1C, the

15   electroconductive film 4 in the present embodiment is often formed in _a_ ~~such~~ structure that ~~it~~ is thick in the central part and becomes thinner toward the periphery.

The substrate 1 can be selected from silica glass, glass containing a reduced amount of impurities such as

20   Na or the like, soda lime glass, a laminate obtained by laying SiO_2 on soda lime glass by sputtering or the like, ceramics such as alumina or the like, an Si substrate, and so on.

A material for the device electrodes 2, 3 opposed

25   to each other can be an ordinary conductive material, which is properly selected, for example, from metals such as Ni, Cr, Au, Mo, W, Pt, Ti, Al, Cu, Pd, and the

like, alloys thereof, printed conductors composed of a metal or a metal oxide such as Pd, Ag, Au, RuO_2, Pd-Ag, or the like and glass or the like, transparent conductive materials such as In_2O_3-SnO_2 or the like,

5   semiconductor conductive materials such as polysilicon or the like, and so on.

The gap L between the device electrodes, the length W of the device electrodes, the shape of the conductive film 4, etc. are designed, taking an

10   application form or the like into consideration. The device electrode gap L is determined preferably in the range of several hundred nm to several hundred μm and more preferably in the range of several μm to several ten μm, taking the voltage placed between the device

15   electrodes or the like into consideration.

The device electrode length W is determined preferably in the range of several μm to several hundred μm, taking the resistance of the electrodes and the electron emission characteristics into

20   consideration and the thickness d of the device electrodes 2, 3 is preferably in the range of several ten nm to several μm.

In addition to the structure illustrated in Figs. 1A, 1B, and 1C, the device can also be constructed in

25   such structure that the conductive film 4 and the opposed device electrodes 2, 3 are stacked in the stated order on the substrate 1.

A material for the conductive film 4 can be selected, for example, from metals such as Pd, Pt, Ru, Ag, Au, In, Pb, and the like, and oxides such as PdO, SnO_2, In_2O_3, PbO, Sb_2O_3, and the like, and a material

5   suitable for the operation conditions in the forming step described hereinafter is selected therefrom as occasion may demand.

The conductive film 4 is preferably a fine particle film comprised of fine particles in order to

10   obtain good electron emission characteristics. The thickness of the conductive film (average thickness) is properly set, taking the step coverage over the device electrodes 2, 3, the resistance between the device electrodes 2, 3, and so on into consideration, and it

15   is normally determined preferably in the range of 1 Å to several hundred nm and more preferably in the range of 1 nm to 50 nm. The resistance, R_s, is in the range of 1×10^2 to 1×10^7 $\Omega/\square$. R_s is a value obtained when a resistance R measured in the longitudinal direction

20   of a thin film having a width of w and a length is defined as $R = R_s (l/w)$, and $R_s = (\rho/t)$, where ρ is the resistivity.

The fine particle film stated herein is a film of aggregation of plural fine particles, the fine

25   structure of which is a state in which some fine particles are individually dispersed and other fine particles are adjacent to each other or are overlapping

with each other (including a state in which some fine

particles are aggregated to form an island structure

as a whole). The sizes of the fine particles are in

the range of several Å to several hundred nm and

5   preferably in the range of 1 nm to 20 nm.

Since the present specification uses the term

"fine particles" frequently, the meaning thereof will

be described below.

In general, small particles are called "fine

10   particles" and particles smaller than those are called

"ultra-fine particles." Particles still smaller than

the "ultra-fine particles" and containing atoms in the

number not more than about several hundred atoms are

often called "clusters."

15   Boundaries between them are not exact, however,

and they vary depending upon how to classify them with

focus on what property. In addition, the "fine

particles" and "ultra-fine particles" are sometimes

together called "fine particles," and the

20   description in the present specification follows this

definition.

For example, "Jikken Butsurigaku Koza (Lectures in

Experimental Physics) 14: Surface and Fine Particles"

(compiled by Tadao Kinoshita and published September 1,

25   1986 by Kyoritsu Shuppan) describes "When fine

particles are stated in this article, they indicate

particles having the diameter of from about 2-3 μm to

about 10 nm and, particularly, when ultra-fine particles are stated, they mean particles having the sizes of from about 10 nm to about 2-3 nm. The both together are sometimes called simply fine particles and the definition is not always precise but is a rough guide. If the number of atoms constituting a particle is 2 to about several tens to several hundreds, it will be called a cluster." (page 195, lines 22 to 26).

Stating in addition, the definition of "ultra-fine particles" by "Hayashi ultra-fine particle project" of Research Development Corporation of Japan defines a much smaller lower limit of particle size, which is as follows.

--"Ultra-fine particle project" (1981 to 1986) of Souzou Kagaku Gijutsu Suishin Seido (Creative Science and Technology Promotion Organization) determined that particles having the size (diameter) in the range of approximately 1 to 100 nm were called "ultra-fine particles." Then, one ultra-fine particle is an aggregate of 100 to 10^8 atoms approximately. From the scale of atoms, the ultra-fine particles are large or giant particles.-- ("Ultra-Fine Particles-Creative Science and Technology," p2, lines 1 to 4, 1988, compiled by Chikara Hayashi, Ryoji Ueda, and Akira Tasaki and published by Mita Shuppan), and --a particle still smaller than the ultra-fine particles, i.e., one particle composed of several to several hundred atoms,

is usually called a cluster.-- (p2, lines 12 to 13 in the same book)

Keeping the ordinary names described above in mind, the "ultra-fine particle" in the present specification indicates an aggregate of many atoms or molecules, the lower limit of particle size of which is several Å to 1 nm approximately and the upper limit of which is about several μm.

The electron-emitting region 5 is comprised of a fissure area formed in part of the conductive film 4, and is dependent on a fissure forming technique described hereinafter. In some cases there exist conductive fine particles having the sizes in the range of several Å to several ten nm inside the electron-emitting region 5. These conductive fine particles contain part or all of elements of the material forming the conductive film 4. The electron-emitting region 5 and the conductive film 4 near it also contain carbon or a carbon compound in some cases.

Next, a method for producing the electron-emitting device of the present embodiment will be described with reference to Figs. 2A, 2B, and 2C. In Figs. 2A, 2B, and 2C, the same portions as those illustrated in Figs. 1A, 1B, and 1C are also denoted by the same reference numerals as those in Figs. 1A, 1B, and 1C.

1) The substrate 1 is cleaned well with a detergent, pure water, and an organic solvent or the

like, the material for the device electrodes is
deposited thereon by vacuum ~~evaporation~~ *vapor deposition*, sputtering, or

the like, and thereafter the device electrodes 2, 3 are

formed on the substrate 1, for example, by the

5   photolithography technology (Fig. 2A).

2) An organometallic solution is dispensed in the

form of a droplet onto the substrate 1 provided with

the device electrodes 2, 3 so as to establish

connection between the device electrodes 2, 3, and is

10   dried and heated to form the conductive film 4 (Fig.

2B). The organometallic solution is a solution of an

organic compound the main element of which is the metal

of the material for the conductive film 4 described

above.

15   In the present embodiment the ink jet method is

preferably applied as a means for dispensing the

organometallic solution in the form of a droplet. When

this ink jet method is adopted, small droplets ranging

from approximately 10 ng to several ten ng can be

20   generated and dispensed to the substrate with good

repeatability and the method necessitates neither

patterning by photolithography nor a vacuum process,

which is thus preferable in terms of productivity.

Devices of the ink jet method that can be used include

25   those of the bubble jet method using an electrothermal

transducer as an energy generating element, those of

the piezo jet method using a piezoelectric device, and

so on. A means for baking the above droplet is
selected from electromagnetic wave irradiation means,
hot air irradiation means, and means for heating the
whole substrate. The electromagnetic wave irradiation

5   means can be one selected, for example, from an
infrared lamp, an argon ion laser, a semiconductor
laser, and so on.

The method for forming the conductive film 4 is
not limited to the above, but the method can be one

10 selected from vacuum *vapor deposition* ~~evapolation~~, sputtering, chemical
vapor deposition, dispersion coating, dipping, spinner
coating, and so on.

3) The next step is a forming step to form the
electron-emitting region (Fig. 2C). Specifically, the

15 substrate 1 on which the device electrodes 2, 3 and the
conductive film 4 are formed is set in a vacuum
apparatus and the inside of the vacuum apparatus is
evacuated well by an evacuation apparatus. After that,
the substrate is heated to increase the temperature and

20 the voltage from an unrepresented power supply is
placed between the device electrodes 2, 3 to effect
energization. Then a gas for promoting reduction or
cohesion of the material for the conductive film 4 is
introduced into the vacuum vessel to locally break,

25 deform, or modify the conductive film 4, whereby the
electron-emitting region 5 of the changed structure is
formed in the structure-changed portion. (Fig. 2C)

In the present embodiment, at the same time as the electron-emitting region 5 is formed by heating the conductive film 4 to the temperature not less than the room temperature, preferably 50 °C or more, and carrying out the energization operation in an atmosphere containing the gas for promoting reduction or cohesion of the conductive film 4 as described above, a cohesion operation is effected in the vicinity of the electron-emitting region. The temperature of the conductive film 4 is increased by current (membrane current) flowing in the conductive film 4 energized and the film at the increased temperature reacts with the gas for promoting reduction or cohesion to be reduced. This further increases the current and part of the conductive film 4 coheres to a structural change locally, thereby forming a fissure.

In an energization operation technique in which the substrate is not heated in the reduction or cohesion gas, adhesion of impurities on the surface of the conductive film 4 impedes the reduction or cohesion reaction between the gas and the material of the conductive film and the reaction starts after the impurities are removed by increase of temperature with energization. Therefore, the power is consumed more than expected. Particularly, there are some cases in which the current does not flow in thin portions of the conductive film because of high resistance and the

temperature is not increased there to impede the

reaction, so as to fail to form the fissure.   In cases

where the power is supplied through wires to which many

devices are connected, excess current flows to increase

5   voltage drops in the wires, whereby devices having

different fissure forms are made with a large

distribution of electron emission characteristics.

In the present embodiment the substrate 1 is

heated to increase the temperature, whereby part of

10   impurities such as water or the like adhering to the

surface of the conductive film are removed to permit

further promotion of the reaction between the reduction

or cohesion gas and the conductive film 4.   The

reduction or cohesion thus proceeds even in the thin

15   portions of the conductive film 4, so that the fissure

is formed from edge to edge of the conductive film 4.

Further, in the case of an electron source comprised of

a plurality of electron-emitting devices or an image-

forming apparatus incorporating the electron source,

20   the energization operation step for forming the

electron-emitting devices can be carried out at lower

current and the voltage drops are lowered in the common

wires, thereby achieving more even electron emission

characteristics and enhancement of uniformity of

25   luminance.

In the present embodiment the temperature at which

the substrate 1 with the conductive film 4 formed

thereon is heated *is* to be retained is properly determined depending upon the material for the conductive film 4. If this temperature is too high, the cohesion reaction will become excessive in the conductive film, so as to

5 fail to form a preferred electron-emitting region in certain cases, or the cohesion will take place throughout the whole area of the conductive film, so that cohering particles will *separate* ~~become apart~~ from each other, so as to lose electric conduction as the overall

10 film in some cases. The upper limit of the retention temperature is preferably not more than 100 °C, for example, where the material of the conductive film is fine particles of PdO.

In the present embodiment the aforementioned

15 forming operation, *as* ~~if~~ explained referring to Figs. 2A, 2B, and 2C, is carried out under such condition that the substrate 1 is heated to a temperature higher than ~~the~~ room temperature by an unrepresented heater and in an atmosphere containing *a* ~~the~~ vapor (gas) for promoting

20 reduction or cohesion of the conductive film 4.

When the conductive film 4 is made of a metallic oxide, the gas for promoting reduction or cohesion of the material for the conductive film 4 can be selected from reducing gases, for example, H_2, CO, CH_4, and so

25 on. A conceivable reason is that cohesion occurs while the metallic oxide is reduced into metal. On the other hand, when the conductive film 4 is metal, promotion of

cohesion does not occur with CO or CH_4, but the cohesion promoting effect is observed with use of H_2.

The above-stated forming step is preferably employed, particularly, in the case of the ink jet method, among the various forming methods of the conductive film 4. When the organometallic solution is dispensed in the form of a droplet as in the case of the ink jet method or the like, thicknesses of the solution dispensed differ depending upon locations because of surface tension of the droplet. Therefore, when the solution is dried and baked to form the conductive film, the conductive film has a distribution of film thicknesses because of the influence from the difference in the thicknesses due to the surface tension. Normally, the conductive film is thick in the center and becomes thinner toward the periphery. There are also cases in which the center is thin and the film becomes thicker onse toward the periphery, depending upon conditions. It is not easy to flatten the film thicknesses of the conductive film in either case.

In cases where the electron-emitting region is formed by the energization operation (forming operation) of the conductive film with the distribution of thicknesses described above, the resultant electron emission characteristics are sometimes inferior to those in the cases using the other forming methods of the conductive film 4.

The first example is a case in which the electron-emitting region is not formed in the peripheral part of the conductive film where the thickness is the smallest, whereby the conductive film becomes

5   continuous there to create a flow path of current. This state is illustrated in Fig. 21. In the figure, numeral 1 designates the substrate, 2 and 3 the device electrodes, 4 the conductive film, and 5 the electron-emitting region. The electron-emitting region 5 is not

10   formed in the peripheral part 211 of the conductive film 4 because of its small thickness. Therefore, the current flows through the peripheral part 211 when the driving voltage is placed between the device electrodes 2, 3. This current does not contribute to emission of electrons

15   ~~electron~~ and thus wastefully increases power consumption, ~~wastefully~~. The electron-emitting device of this structure essentially has nonlinear characteristics and no device current flows substantially below the threshold voltage. When the flow path is created as

20   described above, an ohmic component appears in current-voltage characteristics.

The second example is such that the current flowing in the above energization operation is concentrated in a relatively thick portion to result in

25   increasing the width of the fissure in the electron-emitting region, whereby emission of sufficient electrons ~~electron~~ becomes unlikely to occur ~~sufficiently~~. In this case, because

the effective electron-emitting region is decreased, the number of electrons emitted is decreased.

For the above reasons, the aforementioned forming step is effective, particularly, where the forming method of the conductive film 4 including the droplet dispensing step like the ink jet method or the like is employed.

In the above forming step, waveforms of the voltage applied are preferably pulse waveforms in particular. For applying such pulses, there is a method illustrated in Fig. 4A for continuously applying pulses with a pulse peak height of a constant voltage and a method illustrated in Fig. 4B for applying pulses with increasing pulse peak heights.

First described referring to Fig. 4A is the method for continuously applying pulses with a pulse peak height of the constant voltage. In Fig. 4A T_1 and T_2 represent pulse duration and pulse spacing of voltage waveforms respectively. Preferably, T_1 is set in the range of 1 μsec to 10 msec and T_2 is set in the range of 10 μsec to 10 msec. The peak height (the peak voltage during the energization forming) of triangular waves is properly selected according to the form of the surface conduction electron-emitting device. Under these conditions, the voltage is applied, for example, for several seconds to several ten seconds. The pulse waveforms are not limited to triangular waves, but

can be any desired waveforms such as rectangular waves

and the like. Next, with reference to Fig. 4B, a ~~Next described referring~~ to Fig. 4B is the method

for applying the voltage pulses with increasing pulse

peak heights is described. In Fig. 4B, T_1 and T_2 are the same as T_1

and T_2 in Fig. 4A. The peak heights of the triangular

waves are increased, for example, by steps of about 0.1

V.

The end of the energization forming operation can

be detected in such a manner that a voltage too low to

locally break or deform the conductive film 4 is

applied during the pulse spacing T_2 and the current

flowing at that time is measured. For example, the

energization forming is terminated when the current is

measured with application of the voltage of about 0.1 V

and the resistance calculated therefrom is not less

than 1 MΩ.

4) The device in which the electron-emitting

region 5 is formed in the conductive film 4 is

preferably subjected to an operation called an

activation step. This activation step can change the

device current I_f and emission current I_e remarkably.

The activation step can be carried out by

repetitively applying pulses between the device

electrodes 2, 3, for example, under an ambience

containing gas of an organic substance. This ambience

can be established by making use of organic gas

remaining in the ambience where the inside of the
vacuum vessel is evacuated using an oil diffusion pump
or a rotary pump, for example. In addition, the
ambience can also be obtained by introducing gas of an

5   appropriate organic substance into a vacuum achieved
once by sufficient evacuation by means of an ion pump
or the like. The preferred gas pressure of the organic
substance at this time varies depending upon the form
of the device electrodes described above, the shape of

10   the vacuum vessel, the kind of the organic substance,
etc., and is properly determined depending upon
circumstances. Appropriate organic substances are
aliphatic hydrocarbons of alkane, alkene, and alkyne,
aromatic hydrocarbons, alcohols, aldehydes, ketones,

15   amines, organic acids such as phenol, carboxylic acid,
sulfonic acid, and the like, and so on. Specifically,
the organic substances applicable include saturated
hydrocarbons represented by C_nH_{2n+2} such as methane,
ethane, propane, and the like, unsaturated hydrocarbons

20   represented by the composition formula of C_nH_{2n} or the
like such as ethylene, propylene, and the like,
benzene, toluene, methanol, ethanol, formaldehyde,
acetaldehyde, acetone, methyl ethyl ketone,
methylamine, ethylamine, phenol, formic acid, acetic

25   acid, propionic acid, and so on. This operation causes
carbon or a carbon compound to be deposited on the
device from the organic substance existing in the

ambience, thereby changing the device current I_f and the emission current I_e remarkably.

The carbon or carbon compound is, for example, graphite (including so-called HOPG, PG, and GC; HOPG indicating nearly perfect graphite crystal structure, PG indicating slightly disordered crystal structure having the crystal grains of about 20 nm, and GC indicating much more disordered crystal structure having ~~the~~ crystal grains of about 2 nm) or non-crystalline carbon (indicating amorphous carbon and a mixture of amorphous carbon with fine crystals of the aforementioned graphite), and the thickness thereof is preferably not more than 50 nm and desirably not more than 30 nm.

The judgment of the end of the activation step can be properly made while measuring the device current I_f and the emission current I_e. The pulse duration, the pulse spacing, the pulse peak heights, etc. are properly determined as occasion may demand.

5) The electron-emitting device obtained through these steps is preferably subjected to a stabilization step. This step is a step of exhausting the organic substance from the vacuum vessel. A vacuum evacuation apparatus for evacuating the vacuum vessel is preferably one not using oil in order to prevent oil generated from the apparatus from affecting the characteristics of the device. Specifically, the

vacuum evacuation apparatus can be selected from an absorption pump, an ion pump, and so on.

In cases where in the aforementioned activation step the oil diffusion pump or the rotary pump was used as an evacuation apparatus and the organic gas resulting from the oil component generated therefrom was used, it is necessary to keep the partial pressure of this component as low as possible. The partial pressure of the organic substance in the vacuum vessel should be a partial pressure under which the aforementioned carbon or carbon compound is prevented substantially from being newly deposited which is preferably not more than 1.3×10^{-6} Pa and particularly preferably not more than 1.3×10^{-8} Pa. Further, during the evacuation of the inside of the vacuum vessel, it is preferable to heat the whole vacuum vessel so as to facilitate the exhaust of organic molecules adhering to the inside wall of the vacuum vessel and to the electron-emitting device. The heating condition at this time is desirably such that, the operation is carried out at 80-250 °C, and preferably not less than 150 °C, as long as possible, but the heating condition is not limited particularly to this condition. The heating is carried out under a condition properly selected according to various conditions including the size and shape of the vacuum vessel, the structure of the electron-emitting device, and so on. The pressure

inside the vacuum vessel has to be set as low as possible, and is preferably not more than 1×10^{-5} Pa and more preferably not more than 1.3×10^{-6} Pa.

The ambience during driving after completion of the above stabilization step is preferably that at the time of completion of the stabilization operation, but it is not limited to this. As long as the organic substance is removed well, sufficiently stable characteristics can be maintained even with a little increase of the pressure itself. New deposition of carbon or the carbon compound can be suppressed by employing such vacuum ambience, so that the device current I_f and the emission current I_e become stable.

The basic characteristics of the electron-emitting device of the present invention will be described with an example of the plane type surface conduction electron-emitting device described previously, referring to Fig. 5 and Fig. 6.

Fig. 5 is a schematic diagram showing an example of a vacuum process apparatus, and this vacuum process apparatus also has the function of a measuring and evaluating apparatus. In Fig. 5, the same portions as those illustrated in Figs. 1A, 1B, and 1C are denoted by the same reference symbols as those in Figs. 1A, 1B, and 1C.

In Fig. 5, reference numeral 55 represents a vacuum vessel and 56 an exhaust pump. The electron-

emitting device is placed in the vacuum vessel 55.

Specifically, numeral 1 designates the substrate

forming the electron-emitting device, 2 and 3 the

device electrodes, 4 the conductive film, and 5 the

electron-emitting region. Numeral 51 indicates a power

supply for applying the device voltage V_f to the

electron-emitting device, 50 *indicates* an ammeter for measuring

the device current I_f flowing in the conductive film 4

between the device electrodes 2, 3, 54 *indicates* an anode

electrode for capturing the emission current I_e emitted

from the electron-emitting region 5 of the device, 53 *indicates* a

high-voltage power supply for applying a voltage to the

anode electrode 54, and 52 *indicates* an ammeter for measuring the

emission current I_e emitted from the electron-emitting

region 5. As an example, measurement is carried out

under such conditions that the voltage of the anode

electrode 54 is set in the range of 1 kV to 10 kV and

the distance H between the anode electrode 54 and the

electron-emitting device is in the range of 2 to 8 mm.

Equipment necessary for measurement under a vacuum

atmosphere of a vacuum system or the like (not

illustrated) is provided in the vacuum vessel 55 and is

adapted to perform measurement and evaluation under a

desired vacuum atmosphere.

The exhaust pump 56 is composed of an ordinary

high vacuum system consisting of a turbo pump, a rotary

pump, etc. and an ultra-high vacuum system consisting

of an ion pump etc. The whole of the vacuum process

apparatus in which the substrate of the electron-

emitting device is placed, illustrated herein, can be

heated by a heater not illustrated. Therefore, the

5   steps of the aforementioned energization forming and

after can also be performed using this vacuum process

apparatus.

Fig. 6 is a schematic diagram showing the

relationship of the emission current I_e and device

10   current I_f, measured using the vacuum process apparatus

illustrated in Fig. 5, versus the device voltage V_f.

Fig. 6 is illustrated in arbitrary units, because the

emission current I_e is extremely small compared to the device

current I_f. The abscissa and ordinate both are linear

15   scales.

As is also apparent from Fig. 6, the electron-

emitting device of the present invention has the

following three characteristic properties as to the

emission current I_e.

20   First, this device increases the emission current

I_e suddenly with application of a device voltage of not

less than a certain voltage (which will be called a

threshold voltage; V_{th} in Fig. 6) and the emission

current I_e is rarely detected with a device voltage of

25   not more than the threshold voltage V_{th}. Namely, the

device is a nonlinear device having the definite

threshold voltage V_{th} against the emission current I_e.

Second, because the emission current I_e has monotonically increasing dependence on the device voltage V_f, the emission current I_e can be controlled by the device voltage V_f.

5   Third, emission charge captured by the anode electrode 54 (see Fig. 5) is dependent on the time of application of the device voltage V_f. Namely, the charge amount captured by the anode electrode 54 can be controlled by the time of application of the device

10   voltage V_f.

As understood from the above description, the electron-emitting device of the present invention is an electron-emitting device the electron emission characteristics of which can be controlled readily

15   according to an input signal. By making use of this property, the electron-emitting device of the present invention can be applied to equipment in various fields, including an electron source comprised of a plurality of such electron-emitting devices, an image-

20   forming apparatus, and so on.

Fig. 6 shows the example in which the device current I_f also monotonically increases against the device voltage V_f (hereinafter referred to as "MI characteristics"), but it is noted that there are cases

25   in which the device current I_f demonstrates the voltage-controlled negative resistance characteristics (hereinafter referred to as "VCNR characteristics")

against the device voltage V_f (though not illustrated). These characteristics can be controlled by controlling the aforementioned steps.

Thanks to the characteristic properties of the electron-emitting device of the present invention described above, the electron source comprised of a plurality of such electron-emitting devices permits the emitted electron amount to be readily controlled according to the input signal, even in the image-forming apparatus or the like, and can be applied in various fields.

Application examples of the electron-emitting device of the present invention will be described below. For example, an electron source and an image-forming apparatus can be constructed by arraying a plurality of electron-emitting devices of the present invention on a substrate.

The array configuration of the electron-emitting devices can be selected from a variety of configurations. An example is a ladder-like configuration in which a lot of electron-emitting devices arranged in parallel are connected each at ~the~ both ends, many rows of electron-emitting devices are arranged (in a row direction), and electrons from the electron-emitting devices are controlled by control electrodes (grid electrodes) disposed above the electron-emitting devices and along a direction

perpendicular to the wires (i.e., in a column

direction). Besides, another example is a

configuration in which plural electron-emitting devices

are arrayed in a matrix pattern along the X-direction

and Y-direction, first electrodes of plural electron-

emitting devices arranged in each row are connected to

a common X-directional wire, and second electrodes of

plural electron-emitting devices arranged in each

column are connected to a common Y-directional wire.

This configuration is a so-called simple matrix

configuration. First, the simple matrix configuration

will be detailed below.

The electron-emitting device of the present

invention has the three characteristics described

previously. Namely, electrons emitted from the

electron-emitting device can be controlled by the peak

height and width of a signal pulsed voltage applied between

the opposed device electrodes in a range not less

than the threshold voltage. On the other hand,

electrons are rarely emitted in the range of not more than

the threshold voltage. According to this

characteristic, in the case of the configuration

comprised of many electron-emitting devices, electron

emission amounts can also be controlled for selected

electron-emitting devices, in accordance with an input

signal, by properly applying the pulsed voltage to the

individual devices.

Based on this principle, description will be given

referring to Fig. 7 as to an electron source substrate

obtained by arraying a plurality of surface conduction

electron-emitting devices, which are an embodiment of

5   the electron-emitting device of the present invention.

In Fig. 7, reference numeral 71 designates an electron

source substrate, 72 X-directional wires, and 73 Y-

directional wires. Numeral 74 denotes surface

conduction electron-emitting devices and 75 connecting

10   wires.

The m X-directional wires 72 are comprised of D_{x1},

$D_{x2}, \ldots, D_{xm}$ and can be constructed of a conductive metal

made by vacuum evaporation, printing, sputtering, or

the like. The material, thickness, and width of the

15   wires are designed properly as occasion may demand.

The Y-directional wires 73 are n wires of D_{y1}, $D_{y2}, \ldots,$

D_{yn} and are made in similar fashion to the X-directional

wires 72. An interlayer insulating layer not

illustrated is provided between these m X-directional

20   wires 72 and n Y-directional wires 73, thereby

electrically separating them from each other (where m,

n are both positive integers).

The interlayer insulating layer (not illustrated) is

of SiO_2 or the like made by vacuum evaporation,

25   printing, sputtering, or the like. For example, the

thickness, material, and production method of the

insulating layer are properly set so that the

interlayer insulating layer is formed on the entire surface or in a desired pattern on part of the substrate 71 on which the X-directional wires 72 are formed and, particularly, so that the insulating layer

5   can withstand potential differences at intersecting portions between the X-directional wires 72 and the Y-directional wires 73. The X-directional wires 72 and Y-directional wires 73 are drawn out as external terminals.

10   Pairs of device electrodes (not illustrated) forming the electron-emitting devices 74 are electrically connected each to the m X-directional wires 72 and to the n Y-directional wires 73 by the connecting wires 75 of an electroconductive metal or

15   the like.

The material for the X-directional wires 72 and the Y-directional wires 73, the material for the connecting wires 75, and the material for the pairs of device electrodes may share some or all of the constituent

20   elements or may be different from each other. These materials are properly selected, for example, from the aforementioned materials for the device electrodes. If the material for the device electrodes is the same as the material for the wires, the wires connected to the

25   device electrodes can be regarded as device electrodes.

Connected to the X-directional wires 72 is an unrepresented scanning signal applying means for

applying a scanning signal for selecting a row of
electron-emitting devices 74 aligned in the X-
direction. On the other hand, connected to the Y-
directional wires 73 is an unrepresented modulation
signal generating means for modulating each column of the
electron-emitting devices 74 aligned in the Y-
direction, according to the input signal. A driving
voltage applied to each electron-emitting device is
supplied as a difference voltage between the scanning
signal and the modulation signal applied to the device.

In the above configuration, the individual devices
can be selected and driven independently, using the
simple matrix wiring.

An image-forming apparatus constructed using the
electron source of this simple matrix configuration
will be described referring to Fig. 8, Figs. 9A and 9B,
and Fig. 10. Fig. 8 is a schematic diagram showing an
example of a display panel of the image-forming
apparatus, and Figs. 9A and 9B are schematic diagrams
of fluorescent films used in the image-forming
apparatus of Fig. 8. Fig. 10 is a block diagram showing
an example of driving circuitry for carrying out
display according to TV signals of the NTSC system.
The same portions as those illustrated in Fig. 7 are
denoted by the same reference symbols and are omitted
from the description. The conductive films 4 are
omitted from the illustration for convenience' sake.

In Fig. 8, reference numeral 81 denotes a rear
plate on which the electron source substrate 71 is
fixed, and 86 _denotes_ a face plate in which a fluorescent film
84, a metal back 85, etc. are formed on an inside

5 surface of glass substrate 83. Numeral 82 designates a
support frame, and the rear plate 81 and face plate 86
are connected to the support frame 82 with frit glass
or the like. Numeral 88 is an envelope, which is
sealed, for example, by baking it in the temperature

10 range of 400°C to 500°C in ~~the~~ atmosphere or in
nitrogen for 10 or more minutes.

The envelope 88 is composed of the face plate 86,
support frame 82, and rear plate 81, as described
above. Since the rear plate 81 is provided for the

15 main purpose of reinforcing the strength of the
electron source substrate 71, the separate rear plate
81 does not have to be provided if the substrate 71
itself has sufficient strength. In other words, the
envelope 88 may also be composed of the face plate 86,

20 support frame 82, and substrate 71 by direct sealing of
the support frame 82 to the substrate 71. On the other
hand, it is also possible to construct the envelope 88
with sufficient strength against the atmospheric
pressure by interposing an unrepresented support called

25 a spacer between the face plate 86 and the rear plate
81.

Figs. 9A and 9B are schematic diagrams _showing_ ~~to show~~

fluorescent films. The fluorescent film 84 can be made
of only a fluorescent material in the monochrome case.
In the case of the color fluorescent film, a the
fluorescent film can be made of black conductive

5   material 91, called black stripes (Fig. 9A) or a black
matrix (Fig. 9B) or the like, and fluorescent materials
92. Purposes for provision of the black stripes or the
black matrix are that a mixture of colors or the like
is made unobstructive by blacking the separating

10   portions between the three primary color fluorescent
materials 92 necessary for color display and that a
decrease is suppressed in the contrast because of
reflection of external light on the fluorescent film
84. The black conductive material 91 can be a material

15   containing graphite as a matrix, which is normally
used, or can be any electroconductive material with
little transmission and reflection of light.

A method for coating the glass substrate 83 with
the fluorescent material can be either one selected

20   from a precipitation method, a printing method, and so
on, irrespective of either monochrome or color. The
metal back 85 is normally provided on the inside
surface side of the fluorescent film 84. Purposes for
provision of the metal back are that the luminance is

25   increased by specularly reflecting light traveling to
the inside surface side out of luminescence of the
fluorescent material toward the glass substrate 83,

that it is made to function as an electrode for applying the voltage for acceleration of electron beams, that it protects the fluorescent material from damage due to bombardment of negative ions generated in the envelope, and so on. The metal back can be made by, after production of the fluorescent film, carrying out a smoothing operation (normally called "filming") of the inside surface of the fluorescent film and thereafter depositing Al thereon by vacuum vapor deposition or the like.

The face plate 86 may also be provided with a transparent electrode (not illustrated) on the outside surface side of the fluorescent film 84 in order to enhance electric conduction of the fluorescent film 84.

On the occasion of carrying out the aforementioned sealing, the electron-emitting devices have to be aligned with the respective color fluorescent materials in the color case and thus sufficient alignment is indispensable.

The image-forming apparatus illustrated in Fig. 8 is produced, for example, as follows. Fig. 19 is a schematic diagram to show the schematic structure of an apparatus used for the following steps. In the figure, numeral 190 denotes a bomb, 191 an ampoule, 192 an exhaust pipe, 193 a vacuum chamber, 194 a gate valve, 195 an exhaust device, 196 a pressure gage, 197 a

quadrupole mass spectrometer, 198a, 198b gas intake lines, and 199a, 199b gas intake control devices.

A display panel not subjected to forming yet is prepared. The envelope 88 of the display panel is linked through the exhaust pipe 192 to the vacuum chamber 193 and further connected via the gate valve 194 to the exhaust device 195. The vacuum chamber 193 is equipped with the vacuum gage 196, quadrupole mass spectrometer 197, etc. for measuring the inside pressure and partial pressures of the respective components in an atmosphere. Since it is not easy to directly measure the inside pressure of the envelope 88 or the like, the process conditions are controlled by measuring the pressure or the like in the vacuum chamber 193. The gas intake lines 198 are connected to the vacuum chamber 193 in order to control the atmosphere by further introducing necessary gas into the vacuum chamber 193. The envelope 88 is arranged to be heated to the temperature above the room temperature by a heater not illustrated.

Connected to the other end of each gas intake line 198 is the bomb 190 or the ampoule 191, each storing an introduced substance, as an introduced substance source. Each intake control device 199 for controlling a rate of intake of the introduced substance is provided in the middle of the associated gas intake line 198. The intake control devices 199 can be

specifically selected from valves permitting control of flow rate of leak, such as slow leak valves, mass flow controllers, and so on, and are selected according to the kind of the introduced substance.

5   The inside of the envelope 88 is evacuated by the apparatus of Fig. 19 and forming is carried out.   On this occasion, the envelope 88 is heated to the temperature not less than 50 °C by the unrepresented heater and the cohesion promoting gas according to the

10   present invention is introduced through the gas intake line 198.   On this occasion, the forming can be carried out in such a manner that, for example, as illustrated in Fig. 20, the Y-directional wires 73 are connected to a common electrode 201 and the voltage pulses are

15   applied simultaneously to the devices connected to one of the X-directional wires 72 from a power supply 202 thereof.   The shape of the pulses and the condition for determining the end of the operation can be selected according to the method for producing the electron-

20   emitting device as described previously.

It is also possible to carry out the forming of the devices connected to plural X-directional wires together by successively applying (scrolling) phase-shifted pulses to the plural X-directional wires.

25   After that, the activation step is carried out according to the aforementioned method for producing the electron-emitting device.   Describing in more

detail, after the inside of the envelope 88 is evacuated sufficiently, an ambience containing an organic substance is established by introducing the organic substance through the gas intake line 198 or by

5   carrying out evacuation by the oil diffusion pump or the rotary pump and using the organic substance remaining in the vacuum ambience. In certain cases a substance other than the organic substance is also introduced if necessary. When the voltage is applied

10   to each electron-emitting device in the ambience containing the organic substance, established as described above, the carbon or carbon compound or a mixture thereof is deposited on the electron-emitting region, whereby the electron emission amount increases

15   drastically. A method for applying the voltage to the electron-emitting devices in this activation step can be a method for applying the voltage pulses simultaneously to the devices connected to one directional wire by the similar connection to that in

20   the forming operation.

Subsequent to the above activation step, the stabilization step is carried out according to the aforementioned method for producing the electron-emitting device. Namely, while the temperature is kept

25   in the range of 80°C to 250°C, the envelope 88 is heated and evacuated through the exhaust pipe 192 by the exhaust device 195 not using oil, such as the ion

pump or the absorption pump, up to an ambience from which the organic substance is reduced well, e.g., into the vacuum of about 1×10^{-5} Pa. After that, the exhaust pipe 192 is heated by a burner to be melted, thereby being cut as being sealed.

In order to maintain the pressure after the sealing of the envelope 88, a getter operation may also be carried out. This is an operation for heating a getter (not illustrated) placed at a predetermined position in the envelope 88 by resistance heating, high-frequency heating, or the like immediately before execution of the sealing of the envelope 88 or after the sealing, thereby forming an evaporated film. The getter normally contains the principal component of Ba or the like and the vacuum, for example, 1×10^{-5} Pa or less, is maintained by adsorbing action of the evaporated film. Next, with reference to Fig. 10 is a structural example of the driving circuitry for carrying out television display based on TV signals of the NTSC system on the display panel constructed using the electron source of the simple matrix configuration is described. In Fig. 10, numeral 101 designates an image display panel, 102 a scanning circuit, 103 a control circuit, 104 a shift register, 105 a line memory, 106 a synchronous signal separating circuit, 107 a modulation signal generator, and V_x and V_a dc voltage supplies.

The display panel 101 is connected to the external circuits via the terminals D_{x1} to D_{xm}, the terminals D_{y1} to D_{yn}, and high-voltage terminal 87. Applied to the terminals D_{x1} to D_{xm} are scanning signals for

5 successively driving the electron source disposed in the display panel 101, i.e., the group of electron-emitting devices arranged in the matrix wiring pattern of m rows × n columns, row by row (every n devices). Applied to the terminals D_{y1} to D_{yn} are modulation

10 signals for controlling output electron beams from the respective electron-emitting devices in one row selected by the scanning signal. Supplied to the high-voltage terminal 87 is the dc voltage, for example, of 10 kV from the dc voltage supply V_a, which is an

15 accelerating voltage for imparting sufficient energy for excitation of the fluorescent material to the electron beams emitted from the electron-emitting devices.

The scanning circuit 102 will be described next.

20 This circuit includes m switching devices (schematically indicated by S_1 to S_m in Fig. 10) inside. Each switching device selects either the output voltage of the dc voltage supply V_x or 0 [v] (the ground level) to be electrically connected to the terminals D_{x1} to D_{xm}

25 of the display panel 101. Each switching device S_1 to S_m operates based on a control signal T_{scan} output from the control circuit 103 and can be constructed, for

example, by a combination of switching devices such as FETs.

The dc voltage supply V_x is set to output ~~such~~ such a constant voltage that the driving voltage applied to the devices not scanned is not more than the electron emission threshold voltage, based on the characteristic (electron emission threshold voltage) of the electron-emitting device.

The control circuit 103 has the function to match operations of the respective sections with each other so as to carry out appropriate display based on the image signals supplied from the outside. The control circuit 103 generates control signals of T_{scan}, T_{sft}, and T_{mry} to the respective sections, based on a synchronous signal T_{sync} sent from the synchronous signal separating circuit 106.

The synchronous signal separating circuit 106 is a circuit for separating a synchronous signal component and a luminance signal component from the TV signal of the NTSC system supplied from the outside, which can be constructed using an ordinary frequency separation (filter) circuit or the like. The synchronous signal separated by the synchronous signal separating circuit 106 is comprised of a vertical synchronous signal and a horizontal synchronous signal, which are illustrated as a T_{sync} signal for ~~convenience~~ sake of explanation. The luminance signal component of an image separated from the

TV signal is represented by a DATA signal for convenience sake. This DATA signal is input into the shift register 104.

The shift register 104 is provided for effecting serial/parallel conversion every line of image with the DATA signal serially input in time series and operates based on the control signal T_{sft} sent from the control circuit 103. (In other words, the control signal T_{sft} can also be mentioned as a shift clock of the shift register 104.) Data of one line of image after the serial/parallel conversion (corresponding to driving data for n electron-emitting devices) is output as n parallel signals of I_{d1} to I_{dn} from the shift register 104.

The line memory 105 is a storage device for storing the data of one line of image for a required period and properly stores the contents of I_{d1} to I_{dn} according to the control signal T_{mry} sent from the control circuit 103. The contents stored are output as $I_{d'1}$ to $I_{d'n}$ to be supplied to the modulation signal generator 107.

The modulation signal generator 107 is a signal source for properly driving and modulating each of the electron-emitting devices according to each of the image data $I_{d'1}$ to $I_{d'n}$ and output signals therefrom are applied via the terminals D_{y1} to D_{yn} to the electron-emitting devices in the display panel 101.

As described previously, the electron-emitting

devices of the present invention have the following

basic characteristics as to the emission current I_e.

Namely, the devices have the definite threshold voltage

V_{th} for emission of electrons, so that emission of

electrons occurs only when the voltage not less than V_{th}

is applied. Against voltages not less than the

electron emission threshold, the emission current also

varies according to change of the voltage applied to

each device. From this feature, where the pulsed

voltage is applied to the device, emission of electrons

does not occur, for example, with application of a

voltage not more than the electron emission threshold

voltage, but an electron beam is output with

application of a voltage not less than the electron

emission threshold voltage. On that occasion, the

intensity of the output electron beam can be controlled

by changing the peak height V_m of the pulse. The total

amount of charge of the output electron beam can be

controlled by changing the width P_w of the pulse.

Therefore, a voltage modulation method, a pulse

duration modulation method, and so on can be employed

as a method for modulating the electron-emitting

devices according to the input signal. For carrying

out the voltage modulation method, the modulation

signal generator 107 can be a circuit of the voltage

modulation method capable of generating voltage pulses

of a constant length and properly modulating peak

heights of the voltage pulses according to the input

data. For carrying out the pulse duration modulation

method, the modulation signal generator 107 can be a

5   circuit of the pulse duration modulation method capable

of generating voltage pulses with a constant peak

height and properly modulating the widths of the

voltage pulses according to the input data.

The shift register 104 and the line memory 105 can

10   be of either a digital signal type or an analog signal

type. This is because one point necessary is that the

serial/parallel conversion and storage of image signals

are carried out at predetermined speed.

In the case of the digital signal type, the output

15   signal DATA of the synchronous signal separating

circuit 106 needs to be digitized and it is implemented

by an A/D converter disposed at an output portion of

the synchronous signal separating circuit 106. In

connection therewith, the circuit used in the

20   modulation signal generator 107 differs slightly,

depending upon whether the output signals of the line

memory 105 are digital signals or analog signals.

Namely, in the case of the voltage modulation method

using digital signals, the modulation signal generator

25   107 is, for example, a D/A converter and an amplifier

or the like is added thereto if necessary. In the case

of the pulse duration modulation method, the modulation

signal generator 107 is a circuit, for example, obtained by combining a high-speed oscillator and a counter for counting the number of waves output from the oscillator with a comparator for comparing an

5   output value from the counter with an output value from the memory. An amplifier can also be added for voltage-amplifying the modulation signal modified in pulse duration, output from the comparator, up to the driving voltage of the electron-emitting device, if

10   necessary.

In the case of the voltage modulation method using analog signals, the modulation signal generator 107 can be, for example, an amplifier using an operational amplifier or the like and a level shift circuit or the

15   like can also be added thereto if necessary. In the case of the pulse duration modulation method, for example, a voltage-controlled oscillator (VCO) can be employed and an amplifier can also be added thereto for voltage-amplifying the modulation signal up to the

20   driving voltage of the electron-emitting device, if necessary.

In the image-forming apparatus of the present invention which can be constructed in the above-stated structure, electron emission occurs when the voltage is

25   applied to each electron-emitting device via the external terminals D_{x1} to D_{xm}, D_{y1} to D_{yn} outside the vessel. At the same time, the high voltage is applied

via the high-voltage terminal 87 to the metal back 85

or to a transparent electrode (not illustrated),

thereby accelerating the electron beams. The

fluorescent film 84 is bombarded with the electrons

5   thus accelerated to bring about luminescence, thereby

forming an image.

The structure of the image-forming apparatus

described herein is just an example of the image-

forming apparatus of the present invention and a

10   variety of modifications can be made based on the

technical concept of the present invention. The input

signals were of the NTSC system, but the input signals

are not limited to this system. For example, they can

be signals of the PAL system, the SECAM system, or the

15   like, or signals of systems of TV signals comprised of

more scanning lines than the foregoing systems (for

example, high-definition TV systems including the MUSE

system).

Next, an electron source of the aforementioned

20   ladder-like configuration and an image-forming

apparatus will be described referring to Fig. 11 and

Fig. 12.

Fig. 11 is a schematic diagram showing an example

of an electron source of the ladder-like

25   configuration. In Fig. 11, numeral 110 designates an

electron source substrate and 111 designates electron-emitting

devices. Numeral 112 represents common wires D_1 to D_{10}

for connection of the electron-emitting devices 111,

which are drawn out as external terminals. The

electron-emitting devices 111 are arranged in parallel

rows along the X-direction (which will be called device

5   rows). The electron source is composed of a plurality

of such device rows. Each device row can be driven

independently by placing the driving voltage between

the common wires of each device row. Namely, a

voltage of not less than the electron emission threshold

10   is applied to a device row expected to emit electron

beams, whereas the voltage of not more than the electron

emission threshold is applied to a device row expected

not to emit electron beams. The common wires D_2 to D_9

located between the device rows can also be formed as

15   single integral wires; for example, D_2 and D_3 can be

made as a single integral wire.

      Fig. 12 is a schematic diagram showing an example

of the panel structure in an image-forming apparatus

provided with the electron source of the ladder-like

20   configuration. Numeral 120 denotes grid electrodes,

121 denotes apertures for electrons to pass, D_1 to D_m denote out-of-

vessel terminals, and G_1 to G_n denote out-of-vessel terminals

connected to the grid electrodes 120. Numeral 110

denotes an electron source substrate in which the

25   common wires between the device rows are made in the

form of integral wires. In Fig. 12, the same portions

as those illustrated in Fig. 8 and Fig. 11 are denoted

by the same reference symbols. The conductive films 4 are omitted from the illustration for convenience sake. The image-forming apparatus shown herein is mainly different from the image-forming apparatus of the simple matrix configuration illustrated in Fig. 8 in that the image-forming apparatus herein is provided with the grid electrodes 120 between the electron source substrate 110 and the face plate 86.

In Fig. 12, the grid electrodes 120 are provided between the substrate 110 and the face plate 86. The grid electrodes 120 are given for the purpose of modulating the electron beams emitted from the electron-emitting devices 111 and are provided with circular apertures 121 each per device in order to let the electron beams pass the stripe-shape electrodes perpendicular to the device rows of the ladder-like configuration. The shape and arrangement of the grid electrodes are not limited to those illustrated in Fig. 12. For example, the apertures can be a lot of pass holes in a mesh pattern and the grid electrodes can be located around or near the electron-emitting devices.

The out-of-vessel terminals D_1 to D_m and G_1 to G_n are connected to the control circuit (not illustrated) Modulation signals for one line of image are applied simultaneously to the grid electrode array in synchronism with successive driving (scanning) of the device rows row by row. This permits the image to be

displayed line by line with controlling irradiation of each electron beam onto the fluorescent material.

The image-forming apparatus of the present invention described above can be used as a display device for television broadcasting or a display device for a video conference system, a computer, or the like and in addition, it can also be used as an image-forming apparatus or the like as an optical printer constructed using a photosensitive drum or the like.

Fig. 17 is a diagram showing an example of a configuration of the image-forming apparatus of the present invention adapted to display image information provided from various image information sources, for example, including television broadcasting and the like.

In the figure, numeral 1700 represents a display panel, 1701 a drive circuit of the display panel, 1702 a display panel controller, 1703 a multiplexer, 1704 a decoder, 1705 an I/O interface circuit, 1706 a CPU, 1707 an image-forming circuit, 1708 to 1710 image memory interface circuits, 1711 an image input interface circuit, 1712 and 1713 TV signal receiving circuits, and 1714 an input unit.

The present image-forming apparatus is, of course, arranged to reproduce sound together with display of an image when receiving a signal including both an image signal and a sound signal, for example, like a

television signal; however, description is omitted

herein for circuits, loudspeakers, etc. concerning

reception, separation, regeneration, processing,

storage, etc. of the sound information not directly

5   related to the features of the present invention.

The functions of the respective units will be

described along with the flow of an image signal.

First, the TV signal receiving circuit 1713 is a

circuit for receiving the TV signal transmitted through

10   a wireless communication system, for example, such as

radio waves, space optical communication, or the like.

There are no specific restrictions on the system of the

TV signal received and either system can be selected,

for example, from the NTSC system, the PAL system, the

15   SECAM system, and so on. TV signals comprised of more

scanning lines than those used by such systems, for example,

so-called high-definition TV signals by the MUSE method

etc., are preferred signal sources for taking advantage

of the features of the display panel suitable for

20   large-area display and the large number of pixels.

The TV signal received by the above TV signal

receiving circuit 1713 is output to the decoder 1704.

The TV signal receiving circuit 1712 is a circuit

for receiving the TV signal transmitted through a wire

25   communication system, for example, such as a coaxial

cable, an optical fiber, or the like. Similarly to the

TV signal receiving circuit 1713, there are no specific

restrictions on the system of the TV signal received
and the TV signal received by this circuit is also
output to the decoder 1704.

The image input interface circuit 1711 is a
5   circuit for capturing an image signal supplied from an
image input device, for example, such as a TV camera,
an image reading scanner, or the like, and the image
signal thus captured is output to the decoder 1704.

The image memory interface circuit 1710 is a
10   circuit for capturing an image signal stored in a video
tape recorder (hereinafter referred to as "VTR") and
the image signal thus captured is output to the decoder
1704.

The image memory interface circuit 1709 is a
15   circuit for capturing an image signal stored in a video
disk and the image signal thus captured is output to
the decoder 1704.

The image memory interface circuit 1708 is a
circuit for capturing an image signal from a device
20   storing still image data, such as a still image disk,
and the still image data thus captured is input into
the decoder 1704.

The I/O interface circuit 1705 is a circuit for
connecting the present image display device to an
25   external output device such as a computer, a computer
network, or a printer. This circuit permits
input/output of image data or character and graphic

information and also permits input/output of control

signals and numerical data between the CPU 1706 in this

image-forming apparatus and the outside in certain

cases.

5   The image-forming circuit 1707 is a circuit for

forming image data for display, based on the image data

or the character and graphic information input from the

outside through the I/O interface circuit 1705 or based

on the image data or the character and graphic

10   information output from the CPU 1706. This circuit

incorporates circuits necessary for formation of an image,

for example, including a writable memory for storing

the image data or the character and graphic

information, a read-only memory for storing image

15   patterns corresponding to character codes, a processor

for carrying out image processing, and so on.

The image data for a display formed by this circuit

is output to the decoder 1704 and in some cases it can

also be output through the I/O interface circuit 1705

20   to an external computer network or printer.

The CPU 1706 mainly performs control of operation

of this image display apparatus and operations

concerning formation, selection, and editing of a display

image.

25   For example, the CPU 1706 outputs a control signal to the

multiplexer 1703, it properly selects an image signal

to be displayed on the display panel, or it properly

combines image signals to be displayed. On that occasion the CPU generates a control signal to the display panel controller 1702 according to the image signal to be displayed, to properly control the operation of the display apparatus as to the screen display frequency, the scanning method (for example, either interlace or non-interlace), the number of scanning lines in one screen, and so on. The CPU also directly outputs the image data or the character and graphic information to the image-forming circuit 1707 or makes access to an external computer or memory through the I/O interface circuit 1705 to take in the image data or the character and graphic information.

The CPU 1706 may also be adapted to be engaged in operations for ~~the~~ other purposes than those discussed above. For example, the CPU may be associated directly with the function to form or process information, like a personal computer, a word processor, or the like; or, as described previously, the CPU may be connected to an external computer network through the I/O interface circuit 1705 to perform an operation, for example, such as numerical computation or the like, in cooperation with an external device.

The input unit 1714 is a device through which a user inputs a command, a program, or data to the CPU 1706, which can be selected from a variety of input devices, for example, such as a keyboard, a mouse, a

joy stick, a bar-code reader, a voice recognition unit, and so on.

The decoder 1704 is a circuit for inverting the various image signals input from the circuits 1707 to

5 1713 to three-primary-color signals, or to luminance signals, and I signals and Q signals. The decoder 1704 is desirably provided with an image memory inside, as indicated by a dotted line in the figure. This is for handling the TV signal necessitating the image memory

10 on the occasion of inversion, for example, in the case of the MUSE system and the like. Provision of the image memory facilitates the display of a still image. Moreover, it presents an advantage of facilitating the image processing and editing, including thinning,

15 interpolation, enlargement, reduction, and synthesis of an image, in cooperation with the image-forming circuit 1707 and CPU 1706.

The multiplexer 1703 operates to properly select the display image, based on a control signal supplied

20 from the CPU 1706. Namely, the multiplexer 1703 selects a desired image signal out of the inverted image signals supplied from the decoder 1704 and outputs the selected image signal to the drive circuit 1701. In that case, it is also possible to select

25 image signals in a switched manner within one screen display time, thereby displaying different images in plural areas in one screen, like a so-called multi-

screen television.

The display panel controller 1702 is a circuit for controlling the operation of the drive circuit 1701, based on a control signal supplied from the CPU 1706.

5   Concerning the basic operation of the display panel, the controller outputs a signal for controlling the operational sequence of the power supply (not illustrated) for driving the display panel, to the drive circuit 1701, for example. Concerning the

10   driving method of the display panel, the controller outputs signals for controlling the screen display frequency and the scanning method (for example, either interlace or non-interlace) to the drive circuit 1701, for example. In some cases, the controller outputs

15   control signals associated with adjustment of image quality, such as luminance, contrast, color tone, and sharpness of the display image, to the drive circuit 1701.

The drive circuit 1701 is a circuit for generating

20   a drive signal applied to the display panel 1700 and operates based on an image signal supplied from the multiplexer 1703 and a control signal supplied from the display panel controller 1702.

The functions of the respective units were

25   described above and the structure exemplified in Fig. 17 permits this image-forming apparatus to display the image information supplied from various image

information sources on the display panel 1700.

Specifically, the various image signals, including the

television broadcasting signals etc., are inverted in the

decoder 1704 and thereafter an image signal is properly

5 selected therefrom in the multiplexer 1703. The

selected image signal is input into the drive circuit

1701. On the other hand, the display controller 1702

generates a control signal for controlling the

operation of the drive circuit 1701 according to the

10 image signal to be displayed. The drive circuit 1701

applies a drive signal to the display panel 1700, based

on the image signal and the control signal. This

causes an image to be displayed on the display panel

1700. These sequential operations are systematically

15 controlled by the CPU 1706.

The present image-forming apparatus can display

selected information out of the data stored in the

image memory incorporated in the decoder 1704 and the

data formed by the image-forming circuit 1707 and can

20 also perform the following operations for the image

information to be displayed; for example, image

processing including enlargement, reduction, rotation,

movement, edge enhancement, thinning, interpolation,

color conversion, aspect ratio conversion of image, and

25 so on, and image editing including synthesis, erasing,

connection, exchange, paste, and so on. The apparatus

may also be provided with a dedicated circuit for

carrying out processing and editing of sound

information, similar to the above image processing and

image editing.

Therefore, this single image-forming apparatus can

5   function as a display device for television

C   broadcasting, as terminal equipment for a video

conference, as an image editing device for handling a

still image and a dynamic image, as terminal equipment

of a computer, as terminal equipment for office use

10   such as a word processor and the like, and as a game

device and thus has a very wide application range for

industries or for consumer use.

C   Fig. 17 is ~~just~~ an example of the configuration

where the image-forming apparatus incorporates the

15   display panel using the electron-emitting devices as an

electron beam source and it is needless to mention that

the image-forming apparatus of the present invention is

not limited to only this example.

For example, no trouble will arise even if the

20   circuits associated with the functions that are not

necessary for the purpose of use are omitted out of the

components of Fig. 17. On the other hand, an

additional component may be added depending upon the

purpose of use. For example, where the present image

25   display apparatus is applied as a video telephone, the

apparatus is preferably provided with additional

components such as a video camera, a sound microphone,

an illuminating device, a transmitter-receiver circuit including a modem, and so on.

Since this image-forming apparatus uses the electron-emitting devices as an electron source, the display panel can be made thinner readily, so that the depth of the image-forming apparatus can be decreased. In addition, the display panel using the electron-emitting devices as an electron beam source can be formed readily in a large screen, has high luminance, and is excellent in viewing angle characteristics; therefore, the image-forming apparatus can display an image of strong appeal with full presence and with high visibility. Use of the electron source achieving the stable and high-efficiency electron emission characteristics can realize a bright and high-quality color flat television having a long lifetime.

Examples

[Examples 1 to 3 and Reference Example 1]

In these examples and reference example, the surface conduction electron-emitting devices were constructed in the structure illustrated in Figs. 1A, 1B, and 1C. Steps of producing the devices of the examples and reference example will be described below.

(1) A silicon oxide film 0.5 μm thick was formed on soda lime glass cleaned, by sputtering, and this was used as the substrate 1. Formed on this substrate 1 was a mask pattern of a photoresist ("RD-2000N-41" available

from Hitachi Kasei K.K.) having apertures corresponding
to the pattern of the device electrodes 2, 3. Then Ti
and Pt were successively deposited in the thickness of
5 nm and in the thickness of 30 nm, respectively, by
vacuum vapor deposition. Then the mask pattern of the
photoresist was dissolved with an organic solvent and
the device electrodes 2, 3 made of the Ti/Pt films were
formed by the lift-off method. The device electrode
gap L was 10 μm and the device electrode length W was
300 μm.

(2) In the following step, the conductive film 4
was formed using an ink jet device. The ink jet device
used included components of an ink jet printer ("BJ-10v"
available from CANON Inc.). The organometallic
solution for forming the conductive film 4 was a
solution obtained by dissolving 0.84 g of palladium
acetate monoethanolamine (hereinafter referred to as
"PAME") in 12 g of water. The thermogravimetric (TG)
analysis was conducted in air and X-ray diffraction
(XD) measurement was further carried out. The results
proved that with increase in temperature PAME started
to be decomposed into metal Pd around 170 °C and PdO
started to be produced at 280 °C.

Using the above-stated ink jet device, a droplet
of the aforementioned PAME aqueous solution was
dispensed so as to make connection between the device
electrodes 2, 3 and was dried. This step was repeated

six times.

The droplets dispensed onto the substrate were subjected to the heating/baking operation at 350 °C for ten minutes in the atmosphere, thereby obtaining the conductive film 4 made of fine particles of PdO. This conductive film was substantially of a circular shape having the diameter of about 120 μm and the thickness of about 10 nm near the center.

(3) Then the electron-emitting region 5 was formed by the forming step. The substrate 1 with the conductive film 4 formed as described above was set in the vacuum vessel 55 of the vacuum process apparatus illustrated in Fig. 5 and the inside was evacuated down to 2.7×10^{-4} Pa or less by the evacuation device 56.

Then the above substrate 1 was heated at 50 °C (Example 1), at 100 °C (Example 2), or at 150 °C (Example 3) by a heater (not illustrated). For stabilizing the temperature, this state was maintained for one hour before proceeding to the next step. For a reference purpose, one device was maintained at room temperature (about 25 °C) without heating (Reference Example 1).

The pulse voltage was placed between the device electrodes 2, 3 of each device at each temperature described above. The pulse waveforms were triangular pulses illustrated in Fig. 4A, which had a pulse peak height of 11 V, a pulse duration T_1 of 1 msec, and a

pulse spacing T_2 of 10 msec. Rectangular pulses with

the peak height of 0.1 V were interposed between the

forming pulses to measure the current and the

resistance was detected therefrom.

5   Then a mixture gas of H_2:2 % and N_2:98 % was

introduced into the vacuum vessel 55 up to the pressure

of 5×10^4 Pa. In either device, the current flowing in

the device gradually decreased at the same time as

introduction of the mixture gas, then increased once,

10   and thereafter suddenly decreased. With each of the

devices heated, the resistance soon became over 1 MΩ

and the application of voltage was stopped at that

point. With the device not heated, the application of

voltage was stopped 30 minutes after. At this time the

15   resistance was over 1 MΩ and the I-V characteristics

included a slightly ohmic component.

    (4) The inside of the vacuum vessel 55 was

evacuated and thereafter acetone was introduced

thereinto up to the pressure of 2.7×10^{-1} Pa. The

20   rectangular pulse voltage was placed between the device

electrodes 2, 3, thereby performing the activation

step. The pulse duration T_1 was 0.5 msec, the pulse

spacing T_2 was 10 msec, and the pulse peak height was 15

V. The pulse voltage was applied for 40 minutes.

25   The electron emission characteristics were

measured for each of the electron-emitting devices

produced as described above. Prior to the measurement,

the inside of the vacuum vessel 55 was evacuated while the vacuum vessel 55 and the electron-emitting device were heated at 200°C and at 150°C, respectively, before the pressure reached 1×10^{-6} Pa or less. After this, the measurement was carried out while applying rectangular pulses having a pulse duration $T_1 = 100$ μsec, the pulse spacing $T_2 = 10$ msec, and the peak height of 15 V to the electron-emitting device and applying the voltage of 1 kV to the anode electrode 54. At this time, a spacing H between a electron-emitting device and the anode electrode 54 was 5 mm.

The device current I_f, emission current I_e, and electron emission efficiency η (%) [= $(I_e/I_f) \times 100$] of each device were as follows.

TABLE 1

Device	Forming temp	I_f (mA)	I_e (μA)	η (%)
Ex 1	50°C	1.4	1.5	0.11
Ex 2	100°C	1.3	1.3	0.10
Ex 3	150°C	0.60	0.48	0.08
Ref Ex 1	RT (25°C)	0.90	0.75	0.08

For each device, I_f was measured at 7 V (not more than the threshold for I_f in either device) to measure the ohmic current component. As a result, a current

of about 0.05 mA was measured in the device of

Reference Example 1, but no current was measured with

the other devices. Therefore, it was verified that the

production method of the present invention was

5   effective in order to prevent appearance of the ohmic

current component. (It was, however, found that the

electron emission efficiency was decreased at

temperatures higher than that of Example 3 and it was

thus preferable to carry out the forming in an

10   appropriate temperature range.)

Devices made up to the above step (3) in a the

similar manner to the above devices were taken out and

observed with a scanning electron microscope (SEM) and

a microscopic Raman spectrometer. The shape of the

15   fissure formed by the forming operation was observed

with an SEM and it was found that the fissure was formed

across the entire width of the conductive film in the

devices produced under the same conditions as in

Example 1 and Example 2 but the fissure was not

20   observed in the peripheral part of the conductive film

in the device produced under the same conditions as in

Reference Example 1. In the device produced under the

same conditions as in Example 3, portions with greater

widths of the fissure were clearly more than those in

25   the devices of Examples 1 and 2.

States of reduction of the conductive film were

observed with the microscopic Raman spectrometer and it

was found that the whole conductive film was almost

perfect metal Pd in Example 2 and Example 3 but there

existed a little PdO except for the Pd area 31 around

the fissure in Example 1, as illustrated in Fig. 3.

5   The device of Reference Example 1 was similar to that

of Example 1 but it seemed to include more PdO.

[Reference Examples 2, 3]

        Reference Example 2 and Reference Example 3 were

prepared under the same conditions as Example 1 and as

10   Example 2, respectively, except that in above step (3)

the pulse voltage was applied in a vacuum the pressure

of which was not more than 1×10^{-6} Pa. In Reference

Example 2 the resistance did not exceed 1 MΩ and thus

the application of pulse was stopped 30 minutes after.

15   In Reference Example 3 the resistance exceeded 1 MΩ

after the application of voltage for the time somewhat

longer than in Example 2 but not too long since the

start of the pulse application and thus the application

of pulse was stopped at that time.

20   With each of the above devices, the electron

emission characteristics and the ohmic current

component were measured in the similar fashion to

a fashion

Examples 1 and 2. As a result, the ohmic device

an

current approximately equal to that in Reference

25   Example 1 was measured in Reference Example 2 and the

electron emission characteristics thereof were also

approximately equal to those in Reference Example 1.

The device of Reference Example 3 had little ohmic current but showed I_f = 1.0 mA, I_e = 0.9 mA, and η = 0.09 %, and, therefore, the electron emission characteristics of Examples 1, 2 were superior to those

5   of Reference Example 3. A device prepared by the same steps up to (3) in ~~the~~ a fashion similar ~~fashion~~ to Example 2 was observed with SEM and it was found that the portions with a wider widths of the fissure were slightly more than in Example 2.

10   It became apparent from the results of these reference examples that execution of the forming operation in the H_2 ambience was able to lower the temperature necessary for preventing occurrence of the ohmic current component. It was also verified that the

15   characteristics of the electron-emitting device produced were improved even if the heating condition was the same.

[Example 4]

As the fourth example of the present invention, an

20   image-forming apparatus was constructed, using the electron source as illustrated in Fig. 7, in which a lot of plane type surface conduction electron-emitting devices were arrayed in the simple matrix configuration.

25   A plan view of part of the substrate 1 in which a plurality of electron-emitting devices are arrayed in matrix wiring, associated with the present example, is

taken line

C illustrated in Fig. 13. A cross section along 14-14 in

the figure is shown in Fig. 14 (in which the electron-

emitting region 5 is omitted from the illustration).

Production steps of the electron source according

5 to the present example are shown in Figs. 15A, 15B,

15C, and 15D and Figs. 16E, 16F, and 16G. In Fig. 13

to Figs. 16E, 16F, and 16G the same reference symbols

denote the same portions. Here, numeral 141 designates

an interlayer insulating layer and 142 a contact hole.

10 The steps will be described below.

(Step-a)

A silicon oxide film 0.5 μm thick was formed on

soda lime glass cleaned, by sputtering, to obtain a

substrate 1 and Cr and Au were successively deposited

15 in the thickness of 5 nm and in the thickness of 600

nm, respectively, on the substrate 1 by vacuum

vapor deposition

C evaporation. Thereafter, a photoresist ("AZ1370"

available from Heochst Inc.) was spin-coated by a

spinner and baked. Thereafter, the photomask image was

20 exposed and developed to form a resist pattern of lower

wires 72 expected to become the X-directional wires.

Then the Au/Cr deposited films were wet-etched to form

the lower wires 72 in the desired pattern (Fig. 15A).

(Step-b)

25 Next, the interlayer insulating layer 141 of a

silicon oxide film 1.0 μm thick was deposited by RF

sputtering (Fig. 15B).

(Step-c)

A photoresist pattern for forming the contact

holes 142 was formed on the silicon oxide film

deposited in step-b and, using this as a mask, the

5   interlayer insulating layer 141 was etched to form the

contact holes 142. The etching was RIE (Reactive Ion

Etching) using CF_4 and H_2 gases (Fig. 15C).

(Step-d)

After that, a pattern expected to become the

10   device electrodes 2, 3 and the gaps between the device

electrodes was formed with a photoresist ("RD-2000N-41"

available from Hitachi Kasei K.K.) and Ti and Ni were

successively deposited thereon in the thickness of 5 nm

and in the thickness of 100 nm, respectively, by vacuum

15   vapor deposition. The photoresist pattern was dissolved

with an organic solvent and the Ni/Ti deposited films

were lifted off, thereby forming the device electrodes

2, 3 having a device electrode gap L of 10 μm and an

electrode length of 300 μm (Fig. 15D).

20   (Step-e)

A photoresist pattern of upper wires 73 expected

to become the Y-directional wires was formed on the

device electrodes 2, 3 and thereafter Ti and Au were

successively deposited thereon in the thickness of 5 nm

25   and in the thickness of 500 nm, respectively, by vacuum

vapor deposition. Then unnecessary portions were removed by

the lift-off process to form the upper wires 73 in a

desired pattern (Fig. 16E).

(Step-f)

The PAME aqueous solution used in Example 1 was dropped between the device electrodes 2, 3 in a similar way to Example 1, using an ink jet device similar to that in Example 1. The solution was heated and baked at 350 °C for ten minutes, thereby forming the conductive film 4 made of fine particles of PdO (Fig. 16F).

(Step-g)

A pattern for coating the portions other than the portions of the contact holes 142 with a resist was formed and Ti and Au were successively deposited thereon in a thickness of 5 nm and in a thickness of 500 nm, respectively, by vacuum vapor deposition. Then unnecessary portions were removed by the lift-off process, thereby filling the contact holes 142 (Fig. 16G).

Then an image-forming apparatus was constructed using the not-yet-subjected-to-forming electron source prepared as described above. The process will be described with reference to Fig. 8 and Fig. 9A.

The electron source substrate 71 provided with the many surface conduction electron-emitting devices 74 as described above was fixed on the rear plate 81 and thereafter the face plate 86 (constructed by forming the fluorescent film 84 and metal back 85 on the inside

C surface of *the* glass substrate 83) was placed through the support frame 82 5 mm above the substrate 71. Frit glass was applied onto joint portions of the face plate 86, support frame 82, atmospheric pressure support (not

5   illustrated), and rear plate 81 and baked at 430°C in the atmosphere for ten minutes to seal them. The rear plate 81 was also fixed to the substrate 71 with frit glass.

The fluorescent film 84, which would be made of

10   only the fluorescent material 92 in the monochrome case, was formed in the stripe pattern (Fig. 9A) of the fluorescent materials 92 in the present example; specifically, the fluorescent film 84 was made by first forming the black stripes and applying the three

15   primary color fluorescent materials 92 to the gap portions by the slurry process. The material of the black stripes was a material containing graphite as a matrix, normally well known.

The metal back 85 was provided on the inside

20   surface side of the fluorescent film 84. The metal back 85 was made by, after fabrication of the fluorescent film 84, carrying out a smoothing operation (normally called filming) of the inside surface of the fluorescent film 84 and thereafter depositing Al by

25   vacuum evaporation.

The face plate 86 is sometimes provided with a transparent electrode on the outside surface side of

the fluorescent film 84 in order to further enhance

electrical conduction of the fluorescent film 84, but

sufficient electrical conduction was achieved by only

the metal back 85 in the present example. Therefore,

5 ~~the~~ a transparent electrode was not provided.

In the forming step of the present example, the

vacuum process apparatus schematically shown in Fig. 19

was used, the Y-directional wires were connected to a

common electrode connected to ~~the~~ ground, and the

10 voltage pulses applied to each of the X-directional

wires had a ~~the~~ pulse duration of 1 msec and a ~~the~~ pulse

spacing of 240 msec. Specifically, pulses with a ~~the~~

pulse duration 1 msec and a ~~the~~ pulse spacing 3.3 msec

were generated by the pulse generator and the X-

15 directional wire to which the voltage was applied was

switched to an adjacent line every pulse by a switching

device.

The pulse peak height was 11 V and the pulse

waveforms were rectangular waves. During the forming

20 operation the whole display panel was kept at 100 °C

and the mixture of gas of H_2 and N_2 was introduced at the

same time as the application of pulse, as in the step

(3) of Example 1.

After completion of the above forming step, the

25 activation step was carried out under the same

conditions as in Example 1. In this step the way of

applying the pulses was the same as in the above

forming step, but the pulses were applied every ten

lines of the X-directional wires, because the operation

was unable to be carried out simultaneously for all the

X-directional wires. Therefore, the operation was

5   completed in order.

After this, evacuation was carried on while the

whole display panel was kept at 200°C. When the

pressure in the vacuum chamber reached 1×10^{-5} Pa or

less, the exhaust pipe was heated to be fused and

10   sealed and then a getter device (not illustrated)

placed in the envelope was heated by high frequency to

effect the getter operation.

Necessary driving systems are connected to the

above display panel to form an image-forming apparatus

15   and 5 kV was applied via the high-voltage terminal (87

in Fig. 8) to the metal back to effect luminescence of

the fluorescent film. The luminescence was obtained

with high luminance but with little variations.

[Example 5, Reference Examples 4, 5]

20   The above described only the examples for forming

the conductive film 4 by the ink jet method, but the

following examples illustrate those by which the effect

was also confirmed where the conductive film was made

by other means.

25   As the fifth example of the present invention, an

image-forming apparatus was constructed using the

electron source as illustrated in Fig. 7 in which a lot

of plane type surface conduction electron-emitting

devices were arrayed in the simple matrix

configuration.

In the present example the image-forming apparatus

5   was constructed by the same production steps up to the

forming step except for the conductive film forming

step (f) as in Example 4, using the electron source

substrate in which 720 devices were aligned on each

line of the X-directional wire (upper wire) and 240

10   devices were aligned on each line of the Y-directional

wire. The conductive film was made by the following

step (f').

(Step-f')

A Cr film 100 nm thick was deposited by vacuum

15   *vapor deposition* ~~evaporation~~ and then was patterned, and organic Pd

(ccp4230 available from Okuno Seiyaku K.K.) was spin-

coated thereon by a spinner. It was heated and baked

at 300 °C for ten minutes. The conductive film 4

composed of fine particles of PdO as a matrix, thus

20   formed, had ~~the~~ thickness of 10 nm and ~~the~~ sheet

resistance of 5 × 10^4 Ω/□.

After that, the Cr film 153 and the conductive

film 4 after baked were etched with an acid etchant to

form a desired pattern.

25   With the not-yet-subjected-to-forming electron

source obtained by the above production steps, the

image-forming apparatus was fabricated through ~~the~~

similar steps to those in Example 4, in which during

the forming operation of all the lines the peak height

of voltage was 10 V and the substrate temperature was

100°C, and *an* image display evaluation similar to that

5   in Example 4 was carried out. With the image-forming

apparatus in the present example, dispersion

distribution of luminance was measured for every pixel

and the standard deviation thereof was 10 % or less

with respect to the average. In addition, there was

10   little ohmic current measured.

In Reference Example 4 the substrate temperature

during the forming operation was *the* room temperature,

different from Example 5, and the peak height of

voltage during the forming operation was the same, 10

15   V. The reduction or cohesion reaction did not proceed

in part of the fine particle film of PdO because of the

influence of surface adsorbates or the like, described

previously, and several % of all the devices were

devices having *an* ohmic current of not less than 0.05

20   mA.

In order to reduce the ohmic current of Reference

Example 4, Reference Example 5 was made in such

conditions that the substrate temperature was *the* room

temperature and the peak height of voltage during the

25   forming operation was 14 V. The ohmic current was not

measured with any device. There appeared, however,

devices with decreased electron emission amounts,

because fissures were created in the conductive films 4
to increase the resistance, so as to decrease the
voltage drop amounts due to the wires whereby a high
voltage was applied from the electrodes 2, 3 to the

5   conductive films 4 in which the reduction or cohesion
took place slowly.

It was verified from the above results that the
effect of capability of carrying out the forming
without the same ohmic current and at the lower voltage was

10 achieved even where the conductive film 4 was formed by
the method except for the ink jet method.

The present invention can provide an electron-
emitting device capable of presenting an good electron
emission characteristics, an electron source

15 incorporating such electron-emitting devices, and an
image-forming apparatus.

The present invention can also provide,
particularly, an electron-emitting device capable of
presenting good electron emission characteristics,

20 irrespective of the forming method of the conductive
film, an electron source incorporating such electron-
emitting devices, and an image-forming apparatus.

The present invention can also provide,
particularly, an electron-emitting device capable of

25 presenting good electron emission characteristics
even with the energization operation on the conductive
film having thickness irregularities, an electron

source incorporating such electron-emitting devices, and an image-forming apparatus.

The present invention can also provide, particularly, an electron source having a plurality of electron-emitting devices with little variation in the electron emission characteristics.

The present invention can also provide an image-forming apparatus capable of forming a higher-quality image.